UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR-TR-79-0206	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): HYPERSONIC HEAT TRANSFER TEST PROGRAM IN THE VKI LONGSHOT FACILITY	5. TYPE OF REPORT & PERIOD COVERED: FINAL rept. 1 Dec 77 - 30 Nov 78
	6. PERFORMING ORG. REPORT NUMBER: AVSD-0028-79-CR
7. AUTHOR(s): V. DICRISTINA	8. CONTRACT OR GRANT NUMBER(s): F49620-78-C-0029
9. PERFORMING ORGANIZATION NAME AND ADDRESS: AVCO SYSTEMS DIVISION, 201 LOWELL ST, WILMINGTION, MA 01887	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 2307A1, AL, 61102F
11. CONTROLLING OFFICE NAME AND ADDRESS: AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA, BLDG 410, BOLLING AIR FORCE BASE, D C 20332	12. REPORT DATE: Jan 79
	13. NUMBER OF PAGES: 29
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 32p.	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

LEVEL II

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC RECEIVED MAR 14 1979

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HYPERSONIC FLOW
EXPERIMENTAL TEST
HEAT TRANSFER MEASUREMENT
PRESSURE MEASUREMENT
FLOW VISUALIZATION
ROUGHNESS EFFECTS
INDENTED NOSE SHAPE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of tests was performed in the Longshot Facility of the Von Karman Institute for Fluid Dynamics (VKI) in Rhode-St. Genese, Belgium, in support of USAF Grant AFOSR 78-3474. This post test report is a summary of 16 tests conducted in the Longshot Facility during the periods of 5-16 June 1978 (Phase I) and 18-29 September 1978 (Phase II). The complete test results are included in the VKI post test report. The purpose of these test was to measure local pressure and heat transfer distributions on a concave body configuration over a range of Mach number and Reynolds number conditions. Both small and large → over

DD FORM 1 JAN 73 1473 404 788 UNCLASSIFIED LB

surface roughness body data were obtained at zero and three degrees angle of attack. High speed cine Schlieren Photographs of the model bow shock structure and dynamics were obtained.

ACCESSION for		
NTIS	White Section	☑
DDC	Buff Section	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION/AVAILABILITY CODES		
A		

AFOSR-TR- 79-0206

Hypersonic Heat Transfer Test Program in the VKI Longshot Facility

Test Summary Report

V. DiCristina

19 January 1979

AVSD-0028-79-CR

Contract No. F49620-78-C-0029

Prepared For

Department of the Air Force
Air Force Office of Scientific Research (AFSC)
Bolling Air Force Base, D.C. 20332

Avco Systems Division
201 Lowell Street
Wilmington, Massachusetts 01887

79 03 12 035

CONTENTS

1.0 INTRODUCTION AND SUMMARY

A series of tests were performed in the Longshot Facility of the Von Karman Institute for Fluid Dynamics (VKI) in Rhode-St. Genese, Belgium in support of USAF Great AFOSR 78-3474 This post test report is a summary of sixteen tests conducted in the Longshot Facility during the periods of 5-16 June 1978 (Phase I) and 18-29 September 1978 (Phase II). The complete test results are included in the VKI post test report.

The purpose of these tests was to measure local pressure and heat transfer distributions on a concave body configuration over a range of Mach number and Reynold number conditions. Both small and large surface roughness body data were obtained at zero and three degrees angle of attack.

The calorimeter instrumentation was calibrated at VKI during the period 24-28 April 1978. The instrumented test model was delivered to the VKI facility for the first series of tests on 5 June 1978. All data measurements were made as planned including high speed cine schlieren photographs of the model bow shock structure and dynamics.

The results of the first eight tests are included here, the complete data set including the large roughness body data will be issued as part of the final VKI test report.

2.0 DISCUSSION

2.1 TEST FACILITY

The VKI Longshot facility was used for this program. Longshot differs from a conventional gun tunnel in that a heavy piston is used to compress the nitrogen test gas to very high pressure and temperatures. The test gas is then trapped in a reservoir at peak conditions by the closing of a system of check values. The flow conditions decay monotonically during 20 milliseconds running time as the nitrogen trapped in the reservoir flows through the 6^{o} half angle conical nozzle into the pre-evacuated open jet test chamber. The maximum supply conditions used in these tests are approximately 60,000 lb/in^2 at $1900^{o}K$ to $2350^{o}K$. These conditions provide unit Reynolds numbers of 8.5×10^6 per foot at a Mach number of 16 and 3.5×10^6 at $M = 20$.

2.2 MODEL DESIGN

The test model design was a concave body configuration shown in Figure 1. This model configuration was designated as model M. The model was fabricated from 303 stainless steel having a wall thickness of approximately 0.2 inches. The first series of tests (runs 1-8) were performed with a small 5 mil roughness over the model surface. The rough surface was achieved by sand blasting. The second series of tests (runs 9-16) were performed with large 65 mil roughness elements over the model surface. The large roughness was created by bonding aluminum spheroid particles onto a sprayed adhesive and coated with a sprayed acrylic. The local calorimeter and pressure port areas did not contain roughness elements.

2.3 INSTRUMENTATION

The test model was instrumental with both pressure and heat flux gages. The gage locations are shown in Figure 1. The test model contains eleven heat flux gages and nine pressure taps. Only eight pressure measurement channels were available at the test facility. The last pressure tape on the concave surface was not connected. PCB model 112A21 high resolution pressure tranduces were connected through short flexible tubes to the surface taps.

The heat transfer gages are smooth calorimeter discs fabricated from .004 inch high conductivity copper stock. A 1 mil wire chromel alumel thermocouple is welded to the copper disc which is bonded to an insulating holder. Twenty calorimeters were fabricated and calibrated at the VKI facility. Table I lists the measured calibration constant (C_T) for each gage. The values shown are the coverage of two measurements. The actual measured disc thickness (X_A) is also shown compared with the calculated effective disc thickness (XE). The data was derived from the following relationships:

$$C_T = \frac{\dot{Q}_C}{\Delta E/\Delta t}$$

$$X_E = \frac{C_T}{\rho\, C_P} = .00523\ C_T$$

where: $\dot{Q}_C$ = calibration heat flux
$\Delta E/\Delta t$ = thermocouple EMF output
X_E = Effective gage thickness
C_T = Calibration constant
ρ = Density, copper
C_P = Specific heat, copper

The variations in X_E are due to the thermocouple weld joints.

2.4 TEST MATRIX

The matrix for the sixteen runs made in the Phase I and II test series is shown in Table II. The small surface roughness model is designated as MR1 and the large roughness model as MR2. The pressure and heat transfer gages were intermixed on the model surface as shown in Figure 1. In order to obtain a complete distribution of pressure and heat transfer measurements for the angle of attack cases both a positive and negative incidence angle was run for the same test conditions as shown in Table II.

2.5 TEST RESULTS

The data measurements for each run included surface pressure, heat transfer and schlieren photos of the model flow field.

The model flow field and bow shock structure was recorded using a 6000 spark per second cine schlieren system. Figures 2 and 3 show the recorded bow shock time sequence. As expected the model contour generates an unstable flow field which results in an oscillating bow shock. The observed oscillations indicate a frequency of 1500-2000 cps. The Strouhal number which depends on the flow frequency (f), model diameter (d), and freestream velocity (V_∞) is:

$$St = Df/V_\infty$$

From the observed oscillations the average Strouhal number appears to be St = 0.13 which is about 30% lower than previously observed from tests at $M_\infty = 10$ and $Re_\infty = 8 \times 10^6$ ft^{-1}.

The measured pressure distributions are shown in Figures 4 to 11. The pressure data has been normalized with respect to the measured pitot pressure measurement. The heat transfer distributions are shown in Figures 12 to 19. The heat transfer data are the measured values for each run condition.

TABLE I

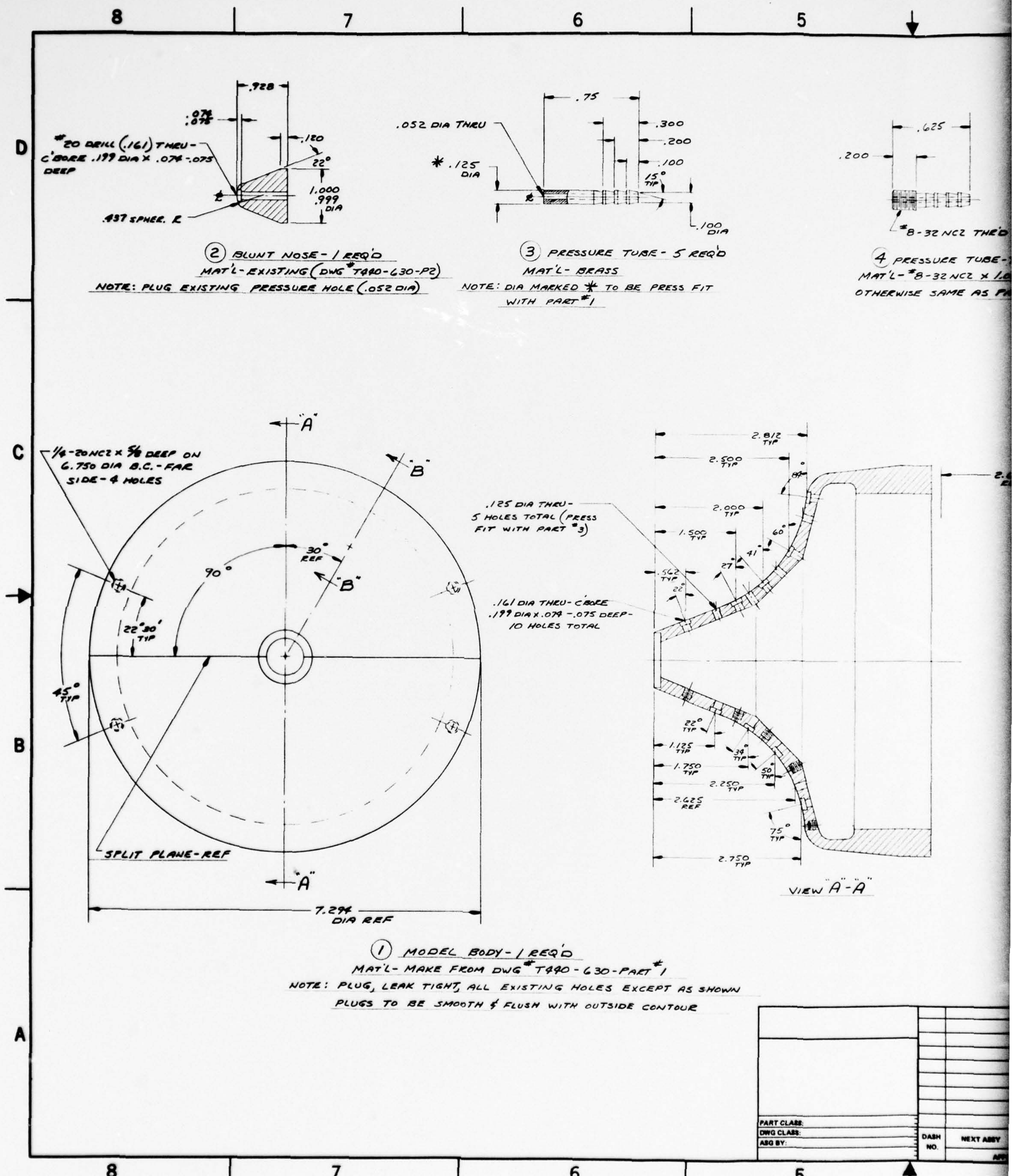
Heat Transfer Gage Calibration Data

Gage No.	Avg. Calib. Coeff., C_T	Effect. Gage Thickness, X_E (in.)	Actual Gage Thickness (in.)
1	.733	.0038	.0031
2	.671	.0035	.0036
3	.530	.0028	.0035
4	.555	.0029	.0038
5	.654	.0034	.0038
6	.548	.0029	.0032
7	.480	.0025	.0034
8	.456	.0024	.0036
9	.495	.0026	.0034
10	.667	.0035	.0038
11	.783	.0041	.0037
12	.951	.0050	.0035
13	.580	.0030	.0031
14	.606	.0032	.0034
15	.612	.0032	.0034
16	.626	.0033	.0037
17	.595	.0031	.0036
18	.585	.0031	.0035
19	.505	.0026	.0036
20	.676	.0035	.0033

TABLE II

VKI Longshot Test Matrix

Run No.	Model	(degree)	M_∞	$Re_\infty (ft^{-1})$
		Phase I		
1	MR1	0	20	2.0×10^6
2	MR1	0	20	3.3×10^6
3	MR1	0	16	4.5×10^6
4	MR1	0	16	8.6×10^6
5	MR1	+3	20	3.3×10^6
6	MR1	-3	20	3.3×10^6
7	MR1	+3	16	6.6×10^6
8	MR1	-3	16	8.6×10^6
		Phase II		
9	MR2	0	20	2.0×10^6
10	MR2	0	20	3.3×10^6
11	MR2	0	16	4.5×10^6
12	MR2	0	16	8.6×10^6
13	MR2	+3	20	3.3×10^6
14	MR2	-3	20	3.3×10^6
15	MR2	+3	16	8.6×10^6
16	MR2	-3	16	8.6×10^6



8
7
6
5
D
C
B
A
.928
.074
.075
.120
#20 DRILL (.161) THRU - C'BORE .199 DIA × .074-.075 DEEP
22°
1.000
.999
DIA
.437 SPHER. R
2 BLUNT NOSE - 1 REQ'D
MAT'L - EXISTING (DWG # T440-630-P2)
NOTE: PLUG EXISTING PRESSURE HOLE (.052 DIA)
.75
.052 DIA THRU
.300
.200
.100
* .125 DIA
15° TYP
.100 DIA
3 PRESSURE TUBE - 5 REQ'D
MAT'L - BRASS
NOTE: DIA MARKED * TO BE PRESS FIT WITH PART # 1
.625
.200
#8-32 NC2 THR'D
4 PRESSURE TUBE-
MAT'L - #8-32 NC2 × 1.
OTHERWISE SAME AS PA
"A"
"B"
1/4-20NC2 × 5/8 DEEP ON 6.750 DIA B.C. - FAR SIDE - 4 HOLES
30° REF
90°
22°30' TYP
45° TYP
SPLIT PLANE - REF
7.294 DIA REF
2.812 TYP
2.500 TYP
2.000 TYP
1.500 TYP
.562 TYP
.125 DIA THRU - 5 HOLES TOTAL (PRESS FIT WITH PART #3)
.161 DIA THRU - C'BORE .199 DIA × .074 - .075 DEEP - 10 HOLES TOTAL
22°
27°
41°
60°
22° TYP
39° TYP
50° TYP
75° TYP
1.125 TYP
1.750 TYP
2.250 TYP
2.625 REF
2.750 TYP
VIEW "A"-"A"
1 MODEL BODY - 1 REQ'D
MAT'L - MAKE FROM DWG # T440 - 630 - PART # 1
NOTE: PLUG, LEAK TIGHT, ALL EXISTING HOLES EXCEPT AS SHOWN
PLUGS TO BE SMOOTH & FLUSH WITH OUTSIDE CONTOUR
PART CLASS:
DWG CLASS:
ASG BY:
DASH NO.
NEXT ASSY

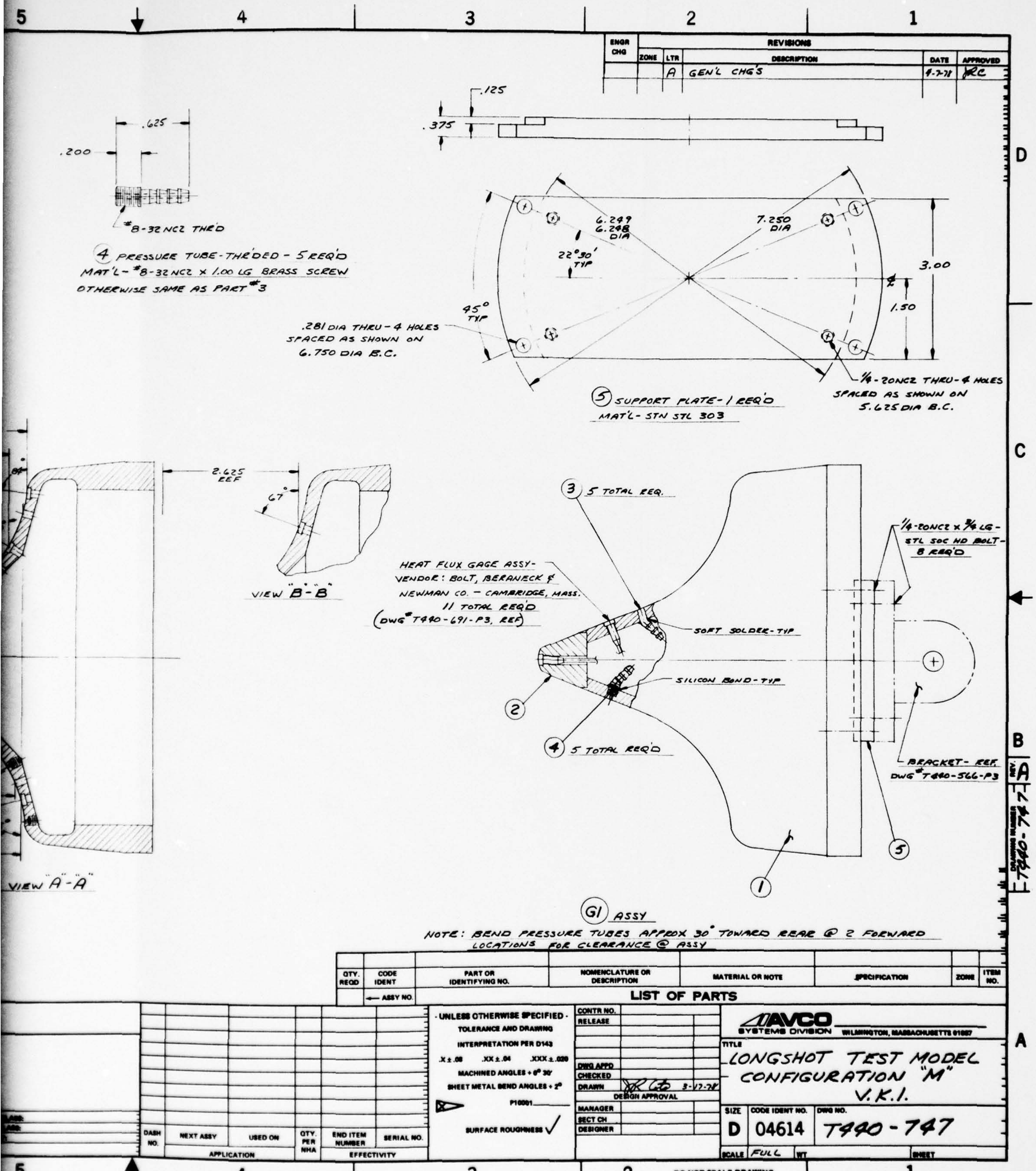
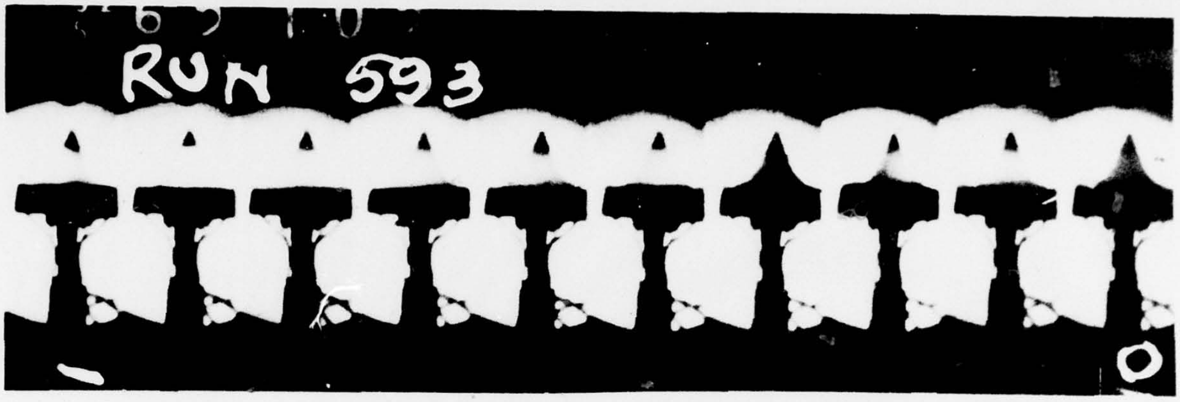
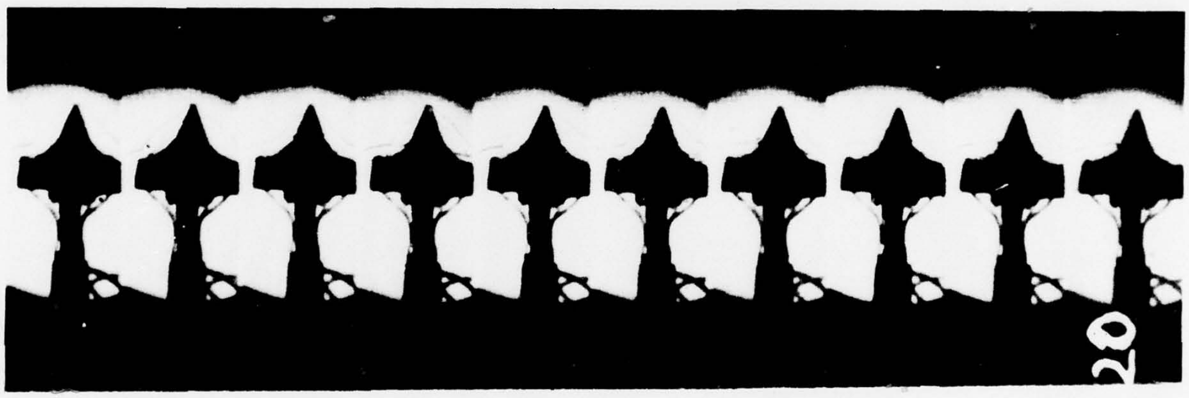

REVISIONS
ENGR CHG
ZONE
LTR
DESCRIPTION
DATE
APPROVED
A GEN'L CHG'S
4-7-78
.125
.375
.625
.200
#8-32NC2 THR'D
4 PRESSURE TUBE-THR'DED - 5 REQ'D
MAT'L - #8-32NC2 x 1.00 LG BRASS SCREW
OTHERWISE SAME AS PART #3
6.249
6.248
DIA
7.250
DIA
22°30'
TYP
3.00
1.50
45°
TYP
.281 DIA THRU - 4 HOLES
SPACED AS SHOWN ON
6.750 DIA B.C.
1/4-20NC2 THRU - 4 HOLES
SPACED AS SHOWN ON
5.625 DIA B.C.
5 SUPPORT PLATE - 1 REQ'D
MAT'L - STN STL 303
2.625
REF
67°
VIEW "B"-"B"
3 5 TOTAL REQ.
1/4-20NC2 x 3/4 LG -
STL SOC HD BOLT -
8 REQ'D
HEAT FLUX GAGE ASSY-
VENDOR: BOLT, BERANECK &
NEWMAN CO. - CAMBRIDGE, MASS.
11 TOTAL REQ'D
(DWG # T440-691-P3, REF)
SOFT SOLDER - TYP
SILICON BOND - TYP
2
4 5 TOTAL REQ'D
BRACKET - REF.
DWG # T440-566-P3
5
1
VIEW "A"-"A"
G1 ASSY
NOTE: BEND PRESSURE TUBES APPROX 30° TOWARD REAR @ 2 FORWARD
LOCATIONS FOR CLEARANCE @ ASSY
QTY. REQD
CODE IDENT
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
MATERIAL OR NOTE
SPECIFICATION
ZONE
ITEM NO.
ASSY NO.
LIST OF PARTS
UNLESS OTHERWISE SPECIFIED
TOLERANCE AND DRAWING
INTERPRETATION PER D143
.X ± .08 .XX ± .04 .XXX ± .030
MACHINED ANGLES ± 0° 30'
SHEET METAL BEND ANGLES ± 2°
SURFACE ROUGHNESS
CONTR NO.
RELEASE
DWG APPD
CHECKED
DRAWN
3-17-78
DESIGN APPROVAL
MANAGER
SECT CH
DESIGNER
AVCO
SYSTEMS DIVISION
WILMINGTON, MASSACHUSETTS
TITLE
LONGSHOT TEST MODEL
CONFIGURATION "M"
V.K.I.
SIZE
CODE IDENT NO.
DWG NO.
D
04614
T440-747
SCALE FULL
WT
SHEET
DASH NO.
NEXT ASSY
USED ON
QTY. PER NHA
END ITEM NUMBER
SERIAL NO.
APPLICATION
EFFECTIVITY
DO NOT SCALE DRAWING
DRAWING NUMBER T440-747
REV. A

FIGURE 1

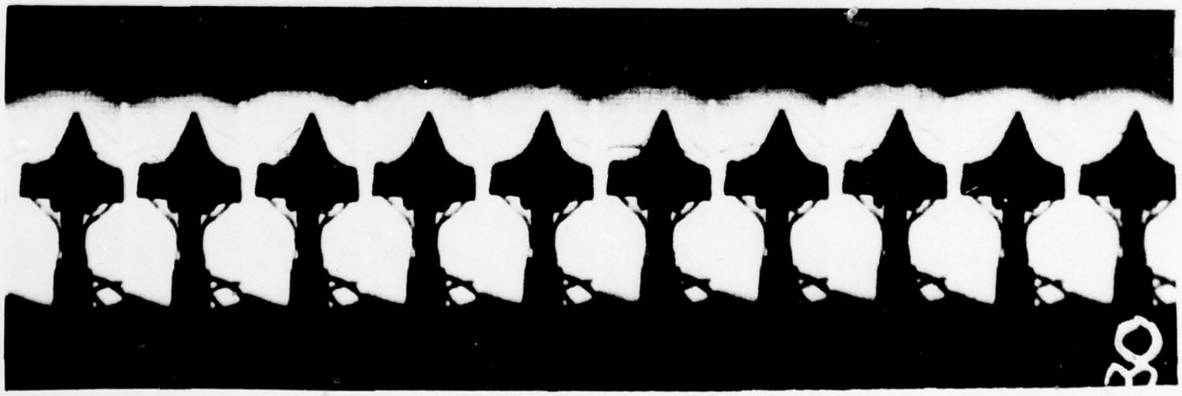
FIGURE 2a
Ciné Schlieren Flow Field
Run No. 593 Model MR1
$M_\infty = 16$, $R_{e_\infty} = 8.6 \times 10^6/\text{ft}$, $\alpha = -3^\circ$



Frame 1 10

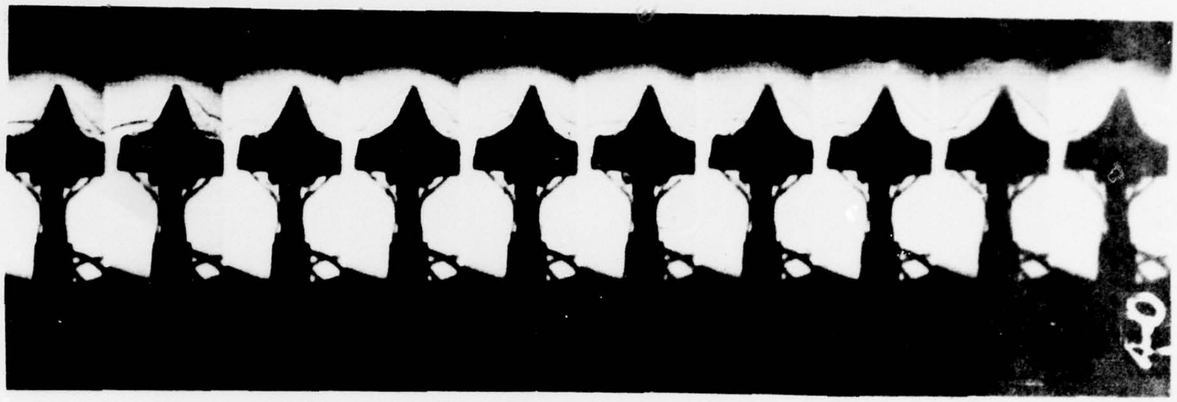


11 20

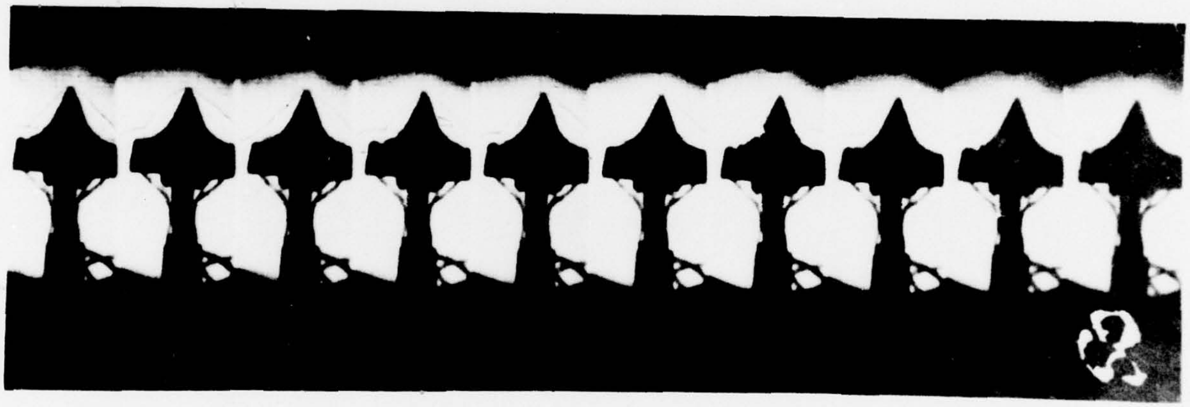


21 30

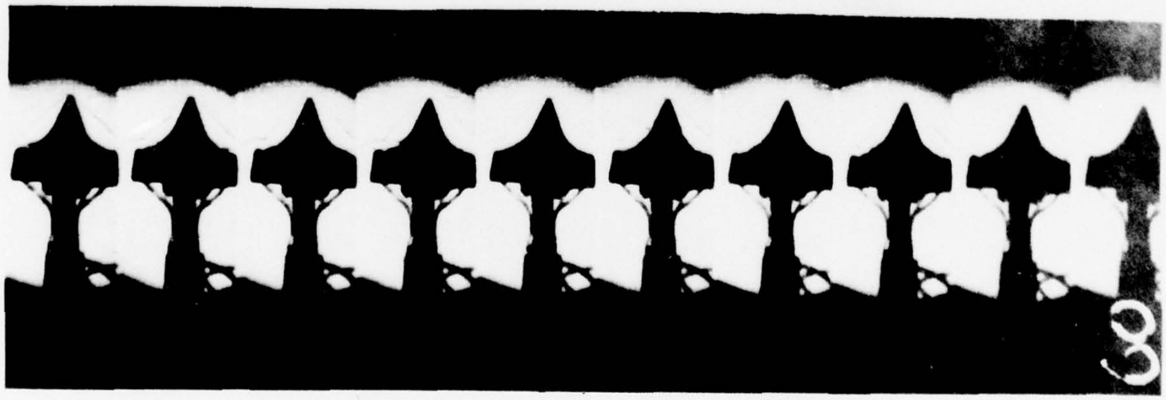
Figure 2b
Ciné Schlieren Flow Field
Run No. 593 Model MR1
$M_{\infty} = 16$, $R_{e_{\infty}} = 8.6 \times 10^6/\text{ft}$, $\alpha = -3^{\circ}$



Frame 31 40

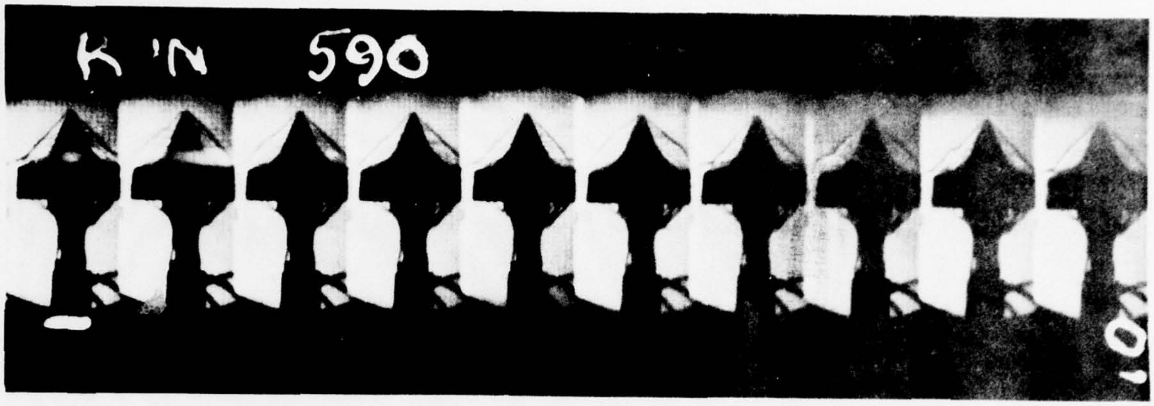


41 50

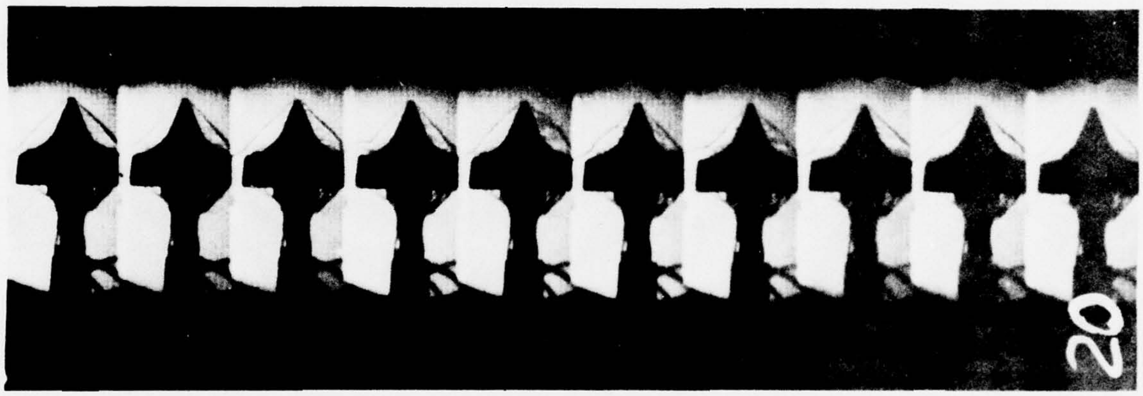


51 60

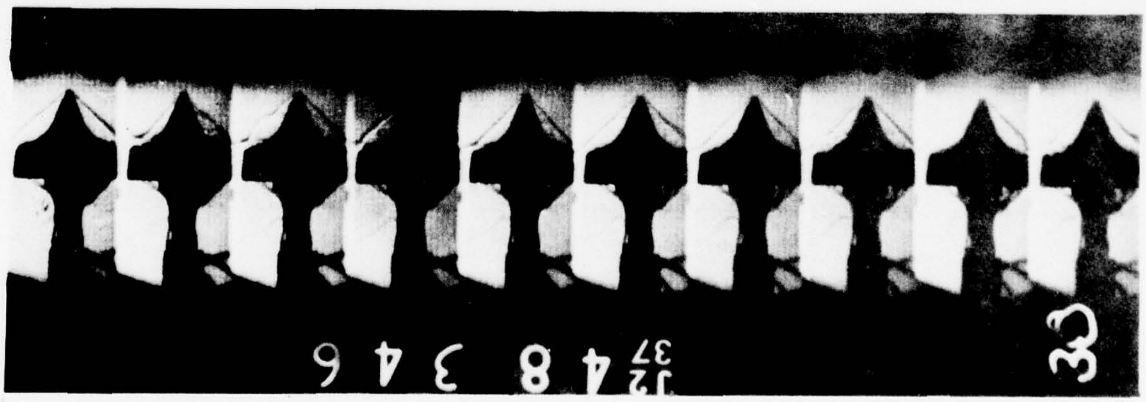
Figure 3a
Cine Schlieren Flow Field
Run No. 590 Model MR1
$M_{\infty} = 20$, $R_{e_{\infty}} = 2.0 \times 10^6$/ft, $\alpha = 0^{\circ}$



Frame 1 10

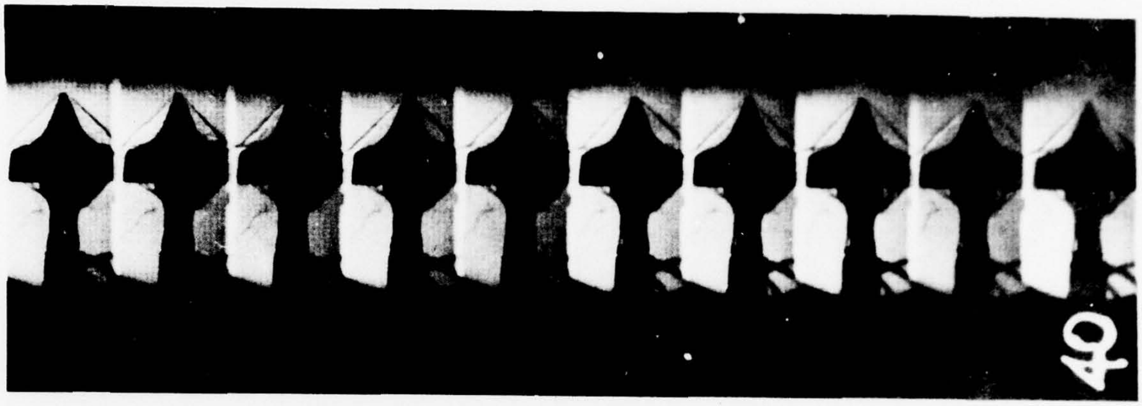


11 20

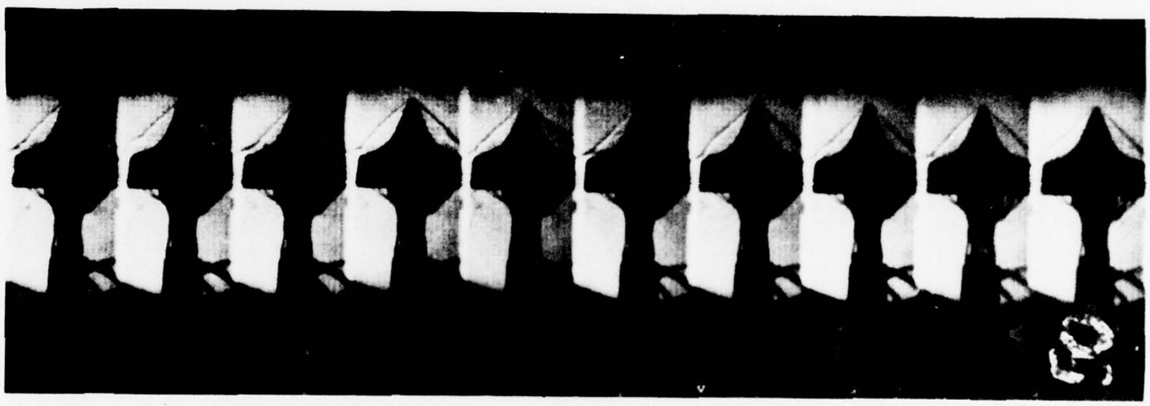


21 30

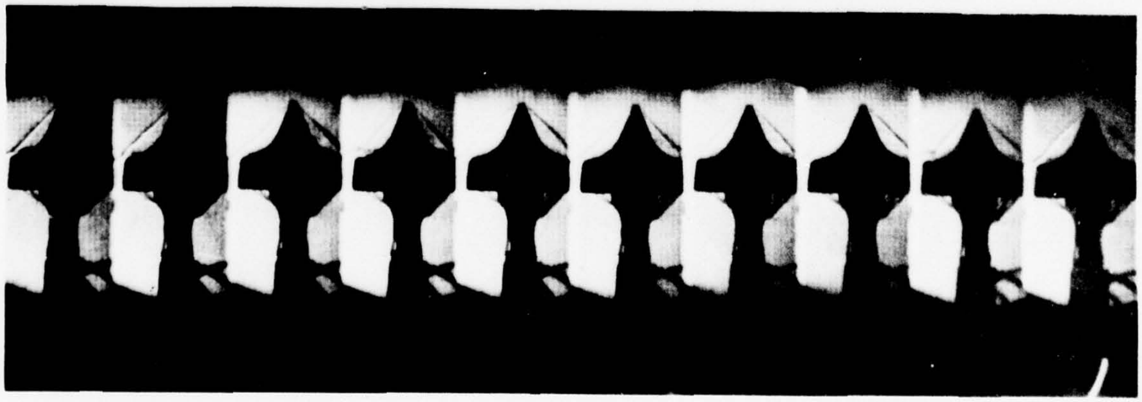
Figure 3b
Cine Schlieren Flow Field
Run No. 590   Model MR1
$M_{\infty} = 20$, $R_{e_{\infty}} = 2.0 \times 10^{6}/\text{ft}$, $\alpha = 0^{\circ}$



Frame 31 | 40



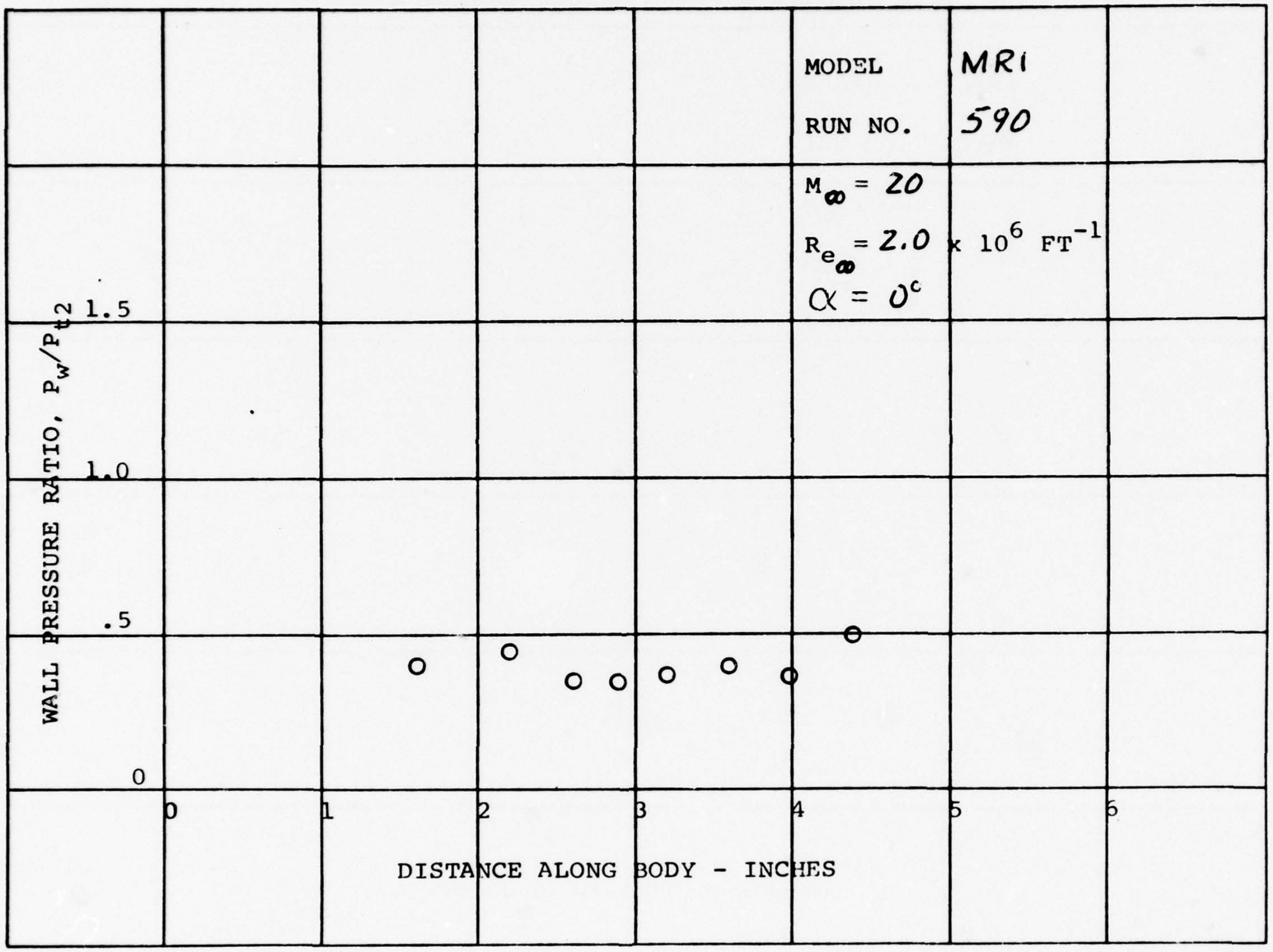
41 | 50



51 | 60

FIGURE NO. 4

WALL PRESSURE ON CONCAVE BICONIC



AVCO

FIGURE NO. 5

WALL PRESSURE ON CONCAVE BICONIC

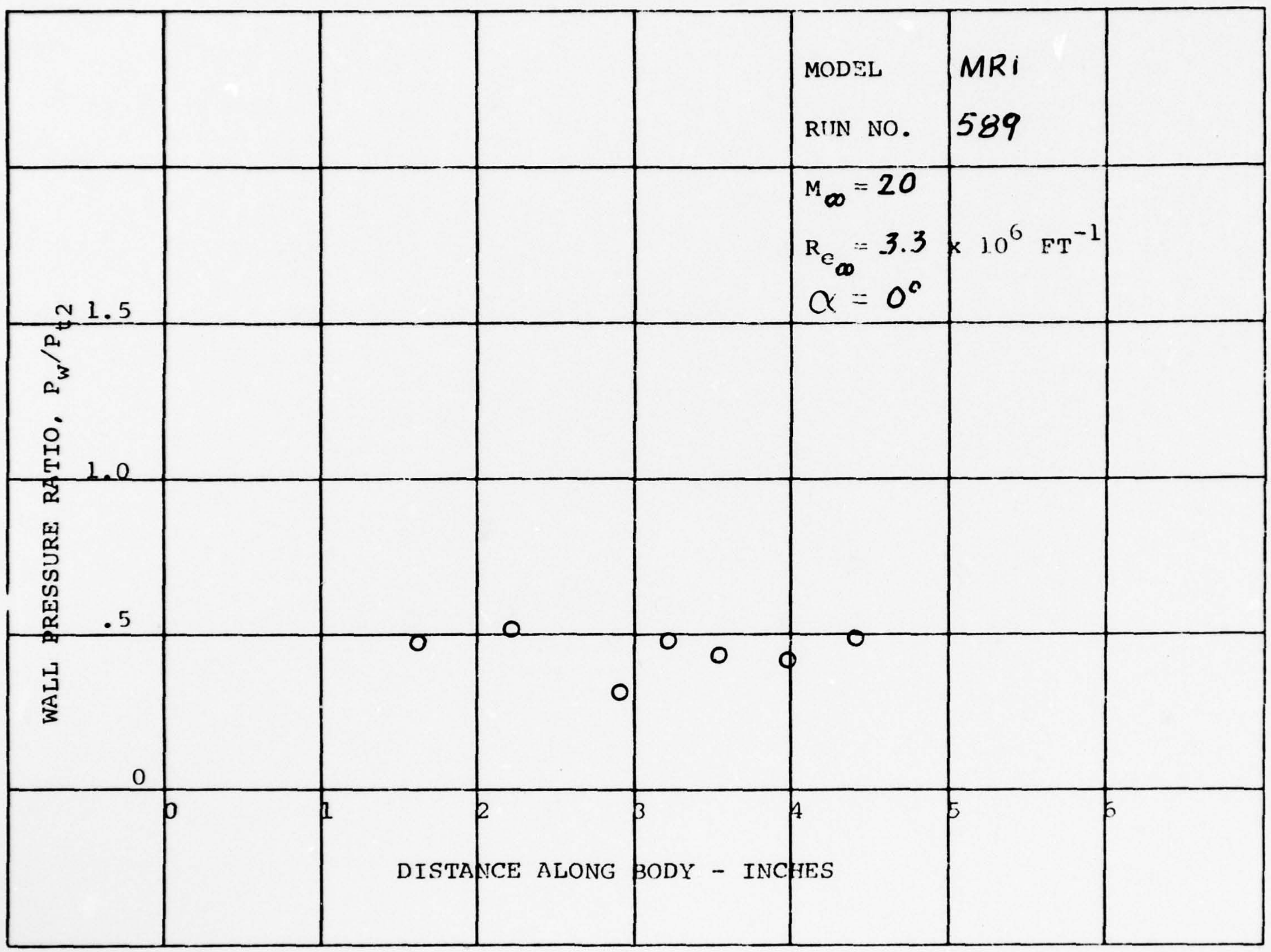
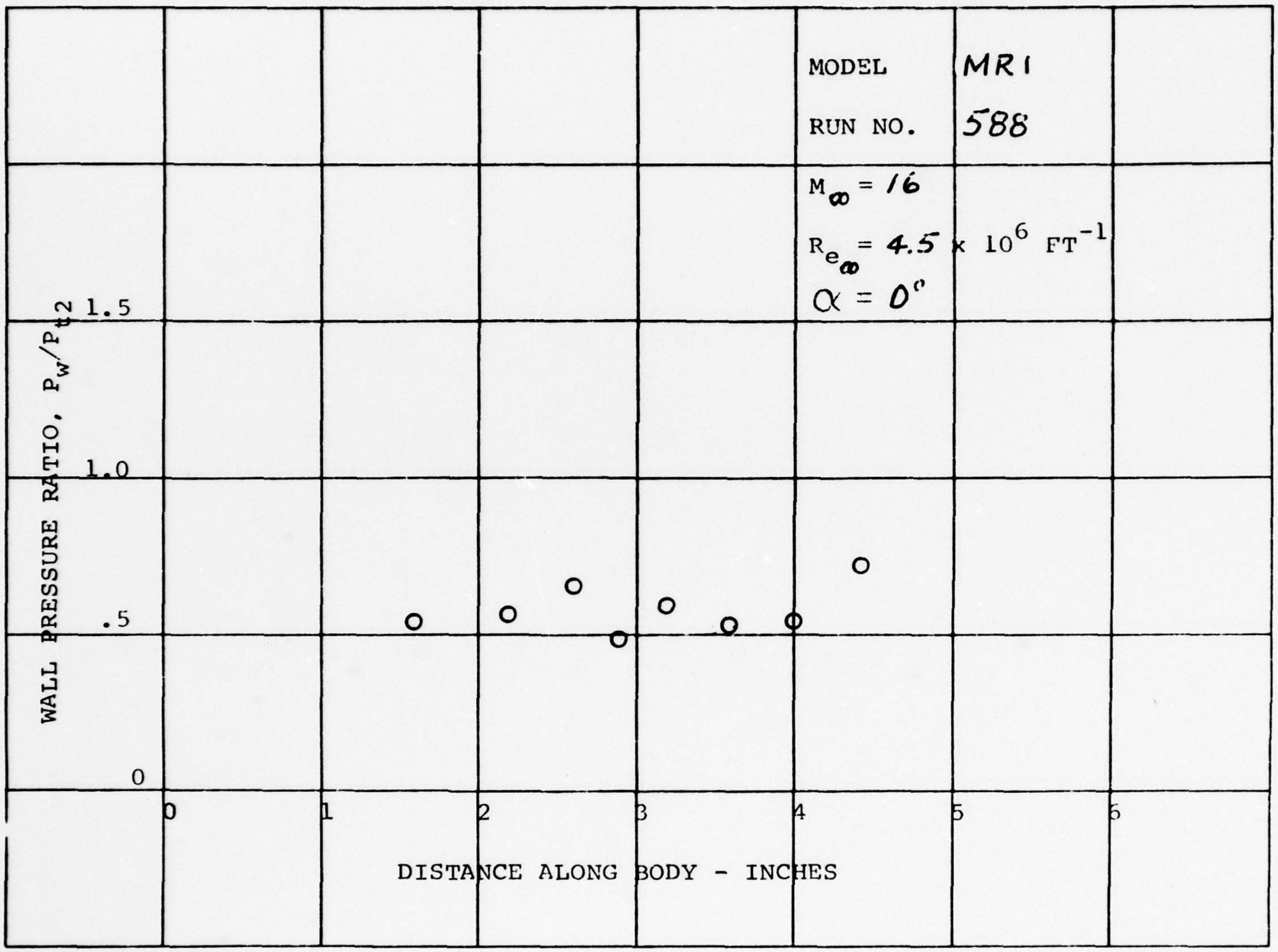


FIGURE NO. 6

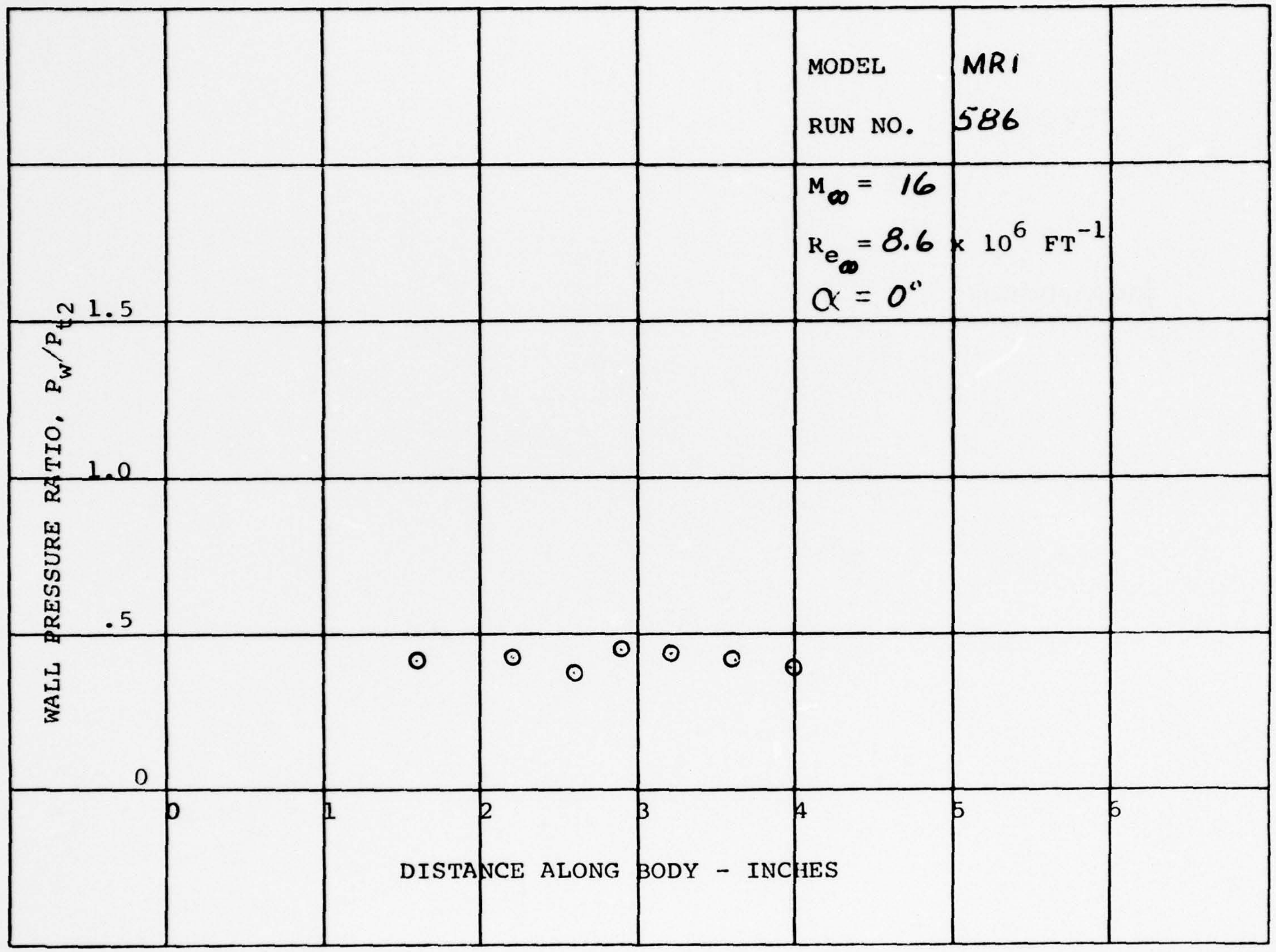
WALL PRESSURE ON CONCAVE BICONIC



AVCO

FIGURE NO. 7

WALL PRESSURE ON CONCAVE BICONIC



AVCO

FIGURE NO. 8

WALL PRESSURE ON CONCAVE BICONIC

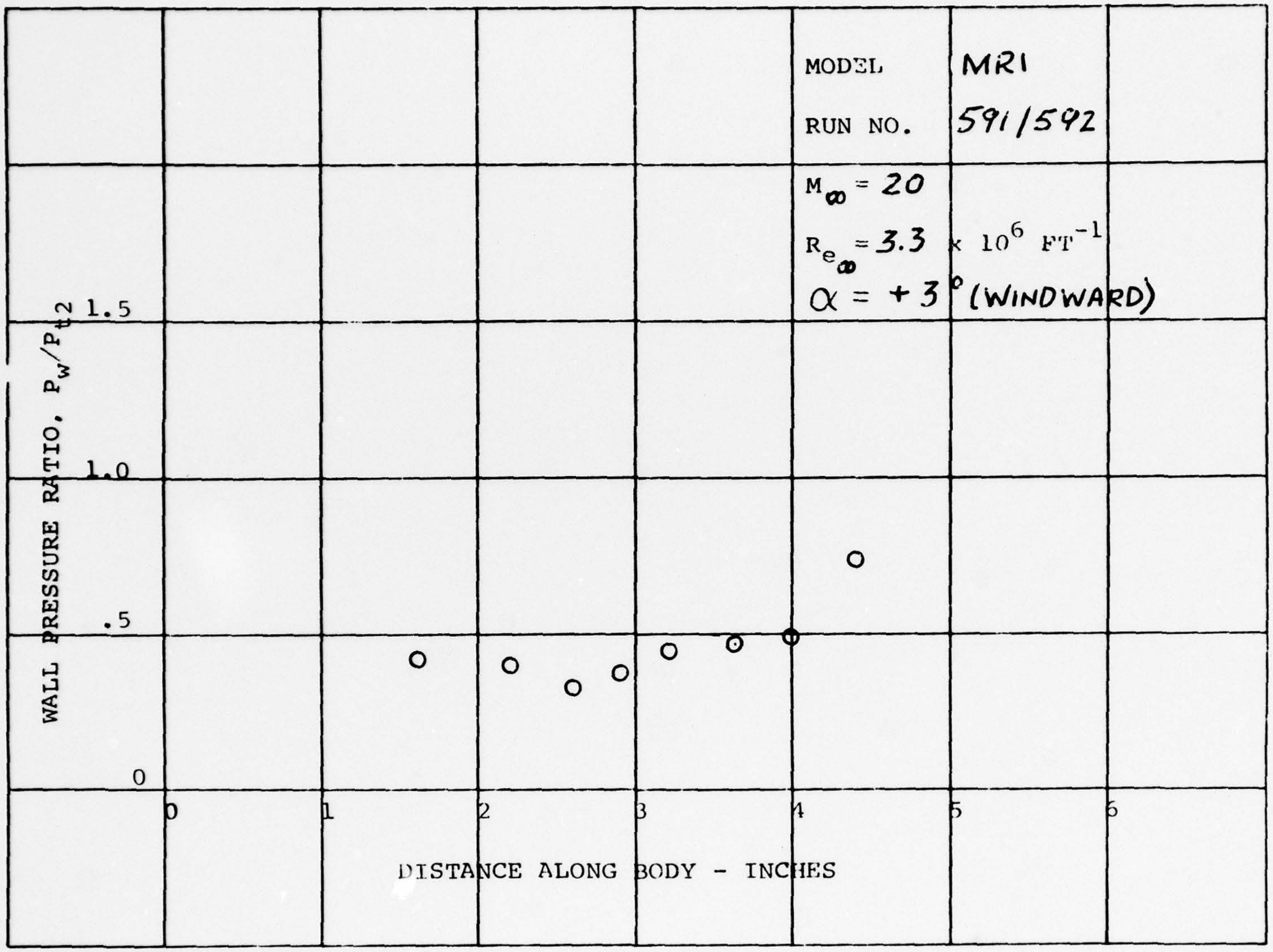
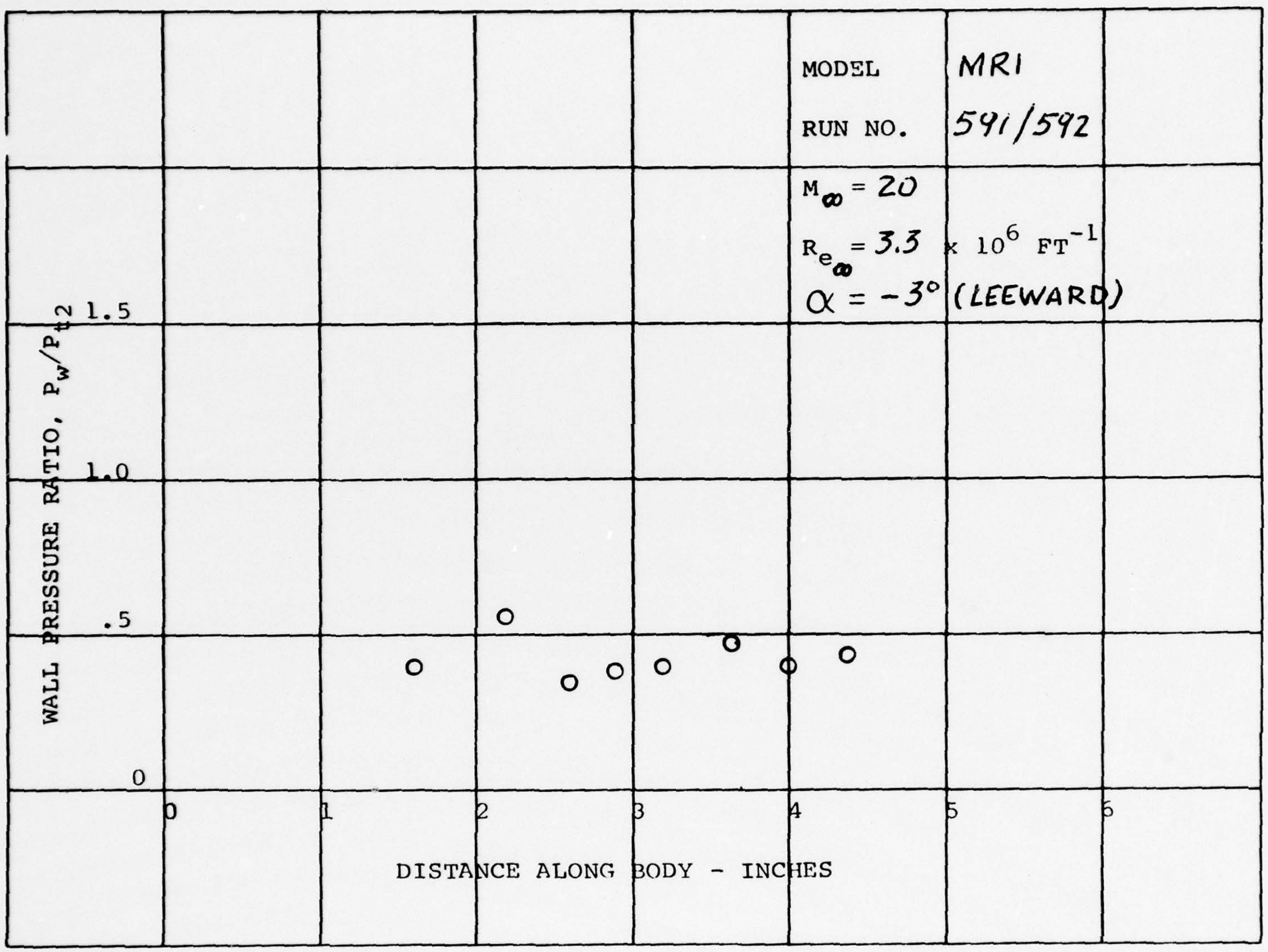


FIGURE NO. 9

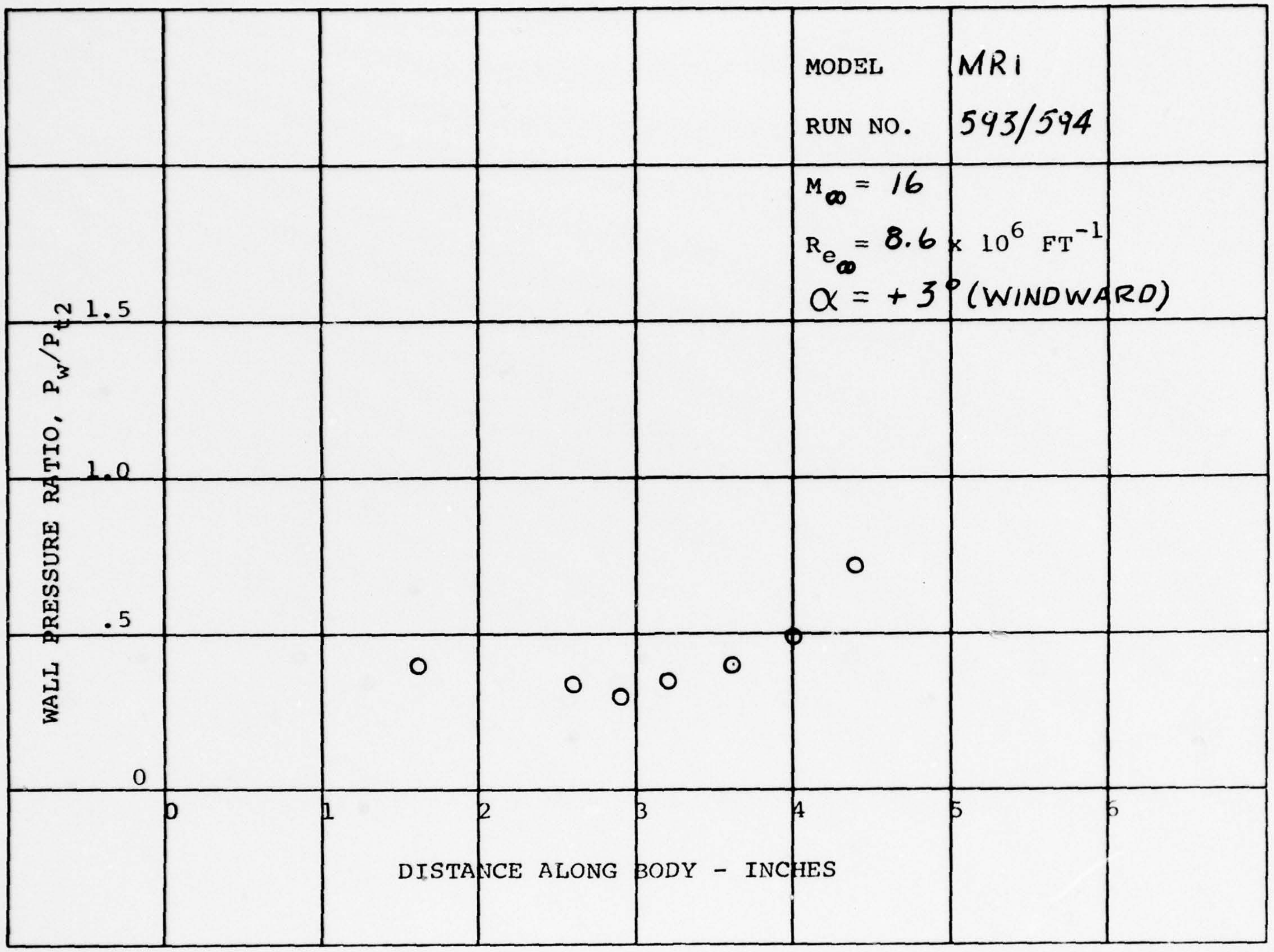
WALL PRESSURE ON CONCAVE BICONIC



AVCO

FIGURE NO. 10

WALL PRESSURE ON CONCAVE BICONIC



AVCO

FIGURE NO. 11
WALL PRESSURE ON CONCAVE BICONIC

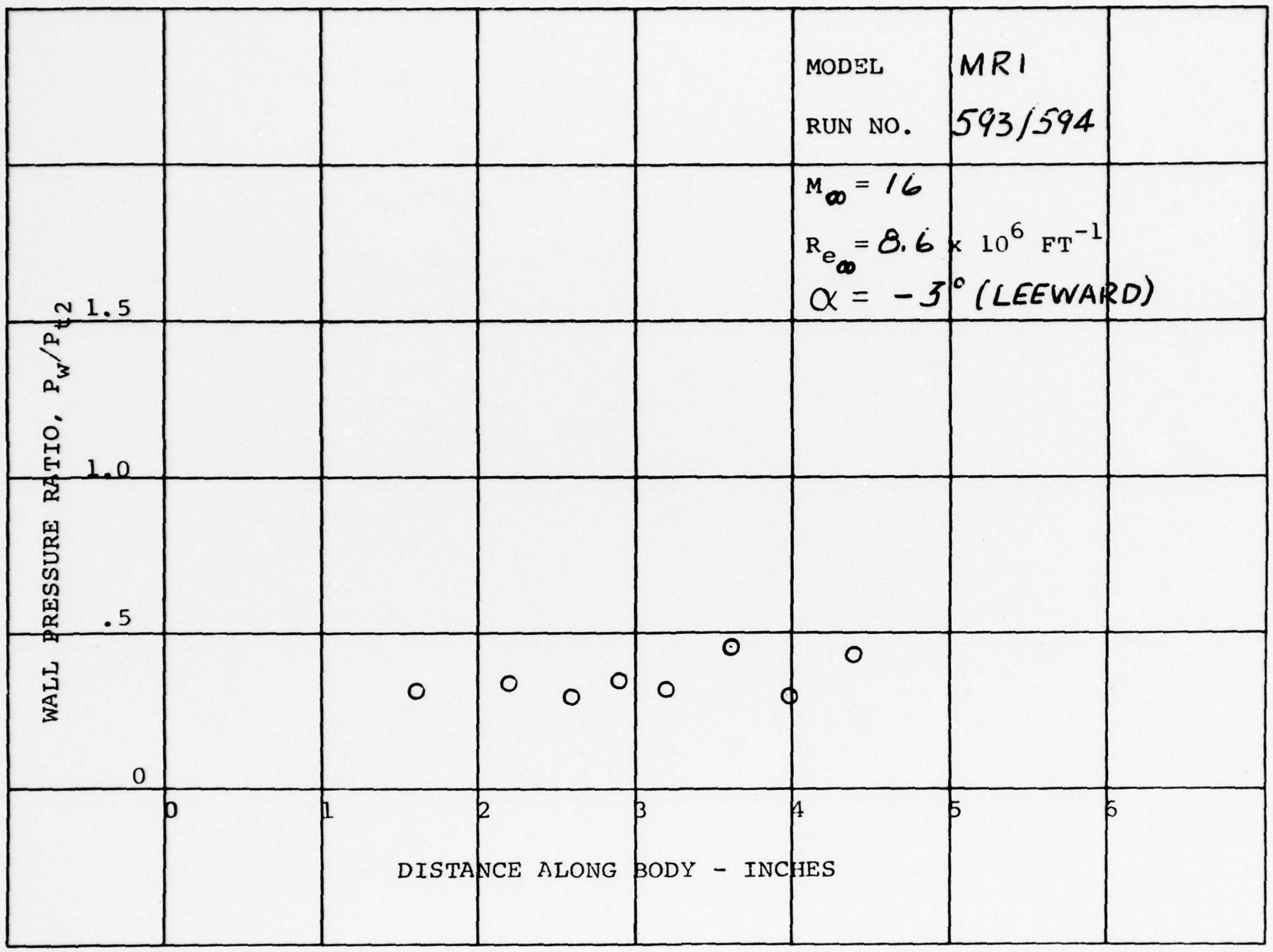
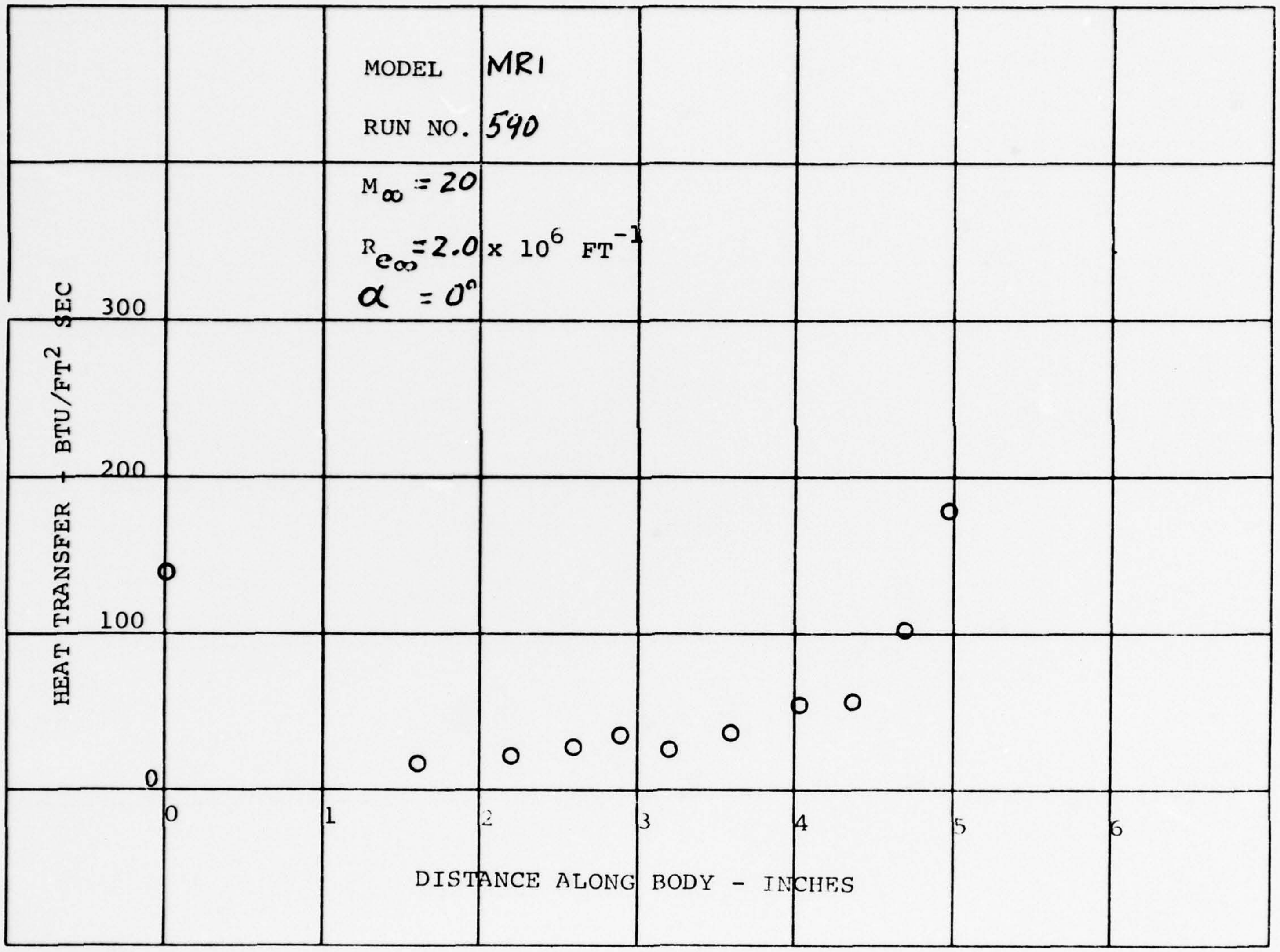


FIGURE NO. 12

HEAT TRANSFER ON CONCAVE BICONIC



AVCO

FIGURE NO. 13

HEAT TRANSFER ON CONCAVE BICONIC

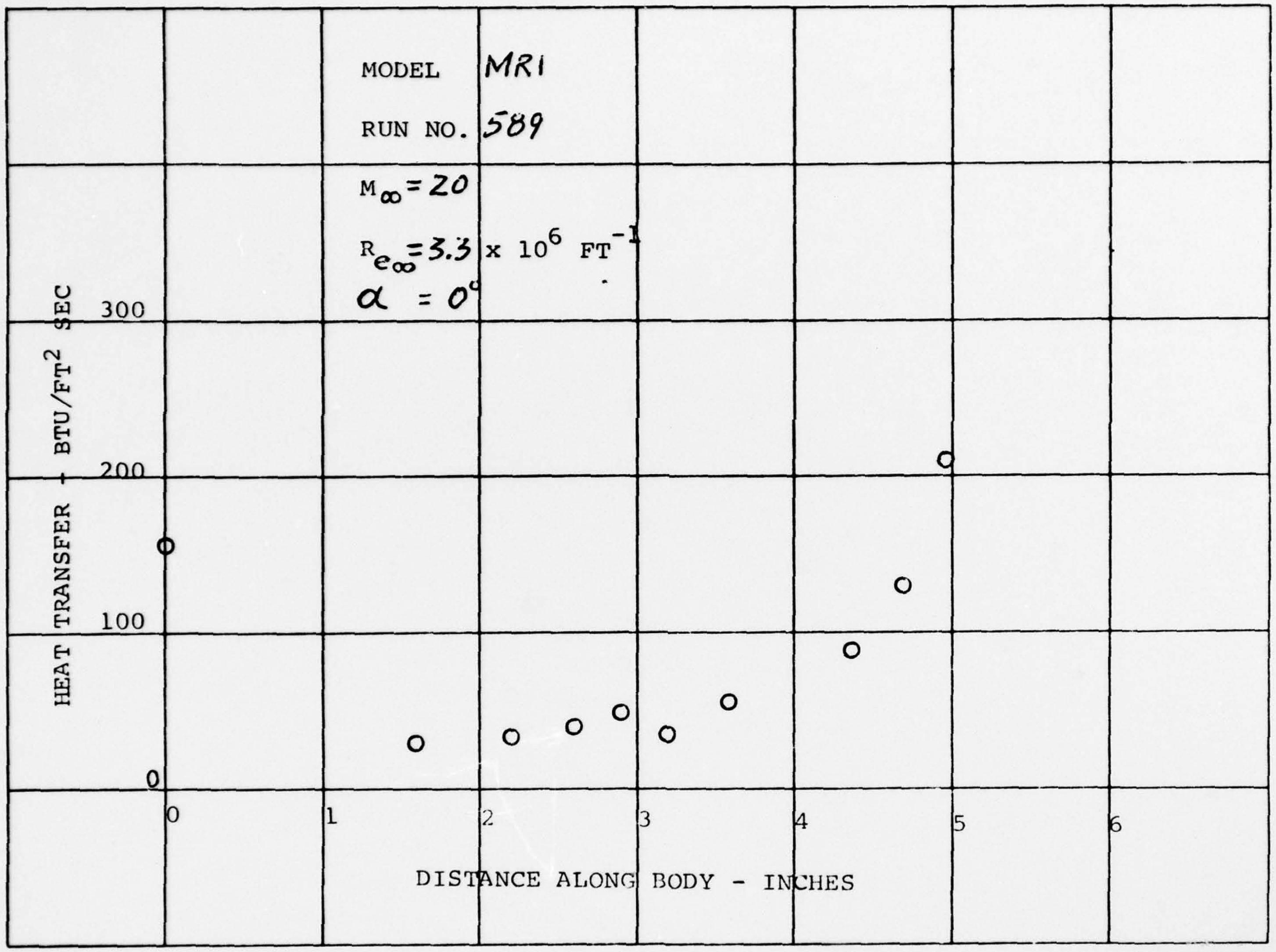


FIGURE NO. 14

HEAT TRANSFER ON CONCAVE BICONIC

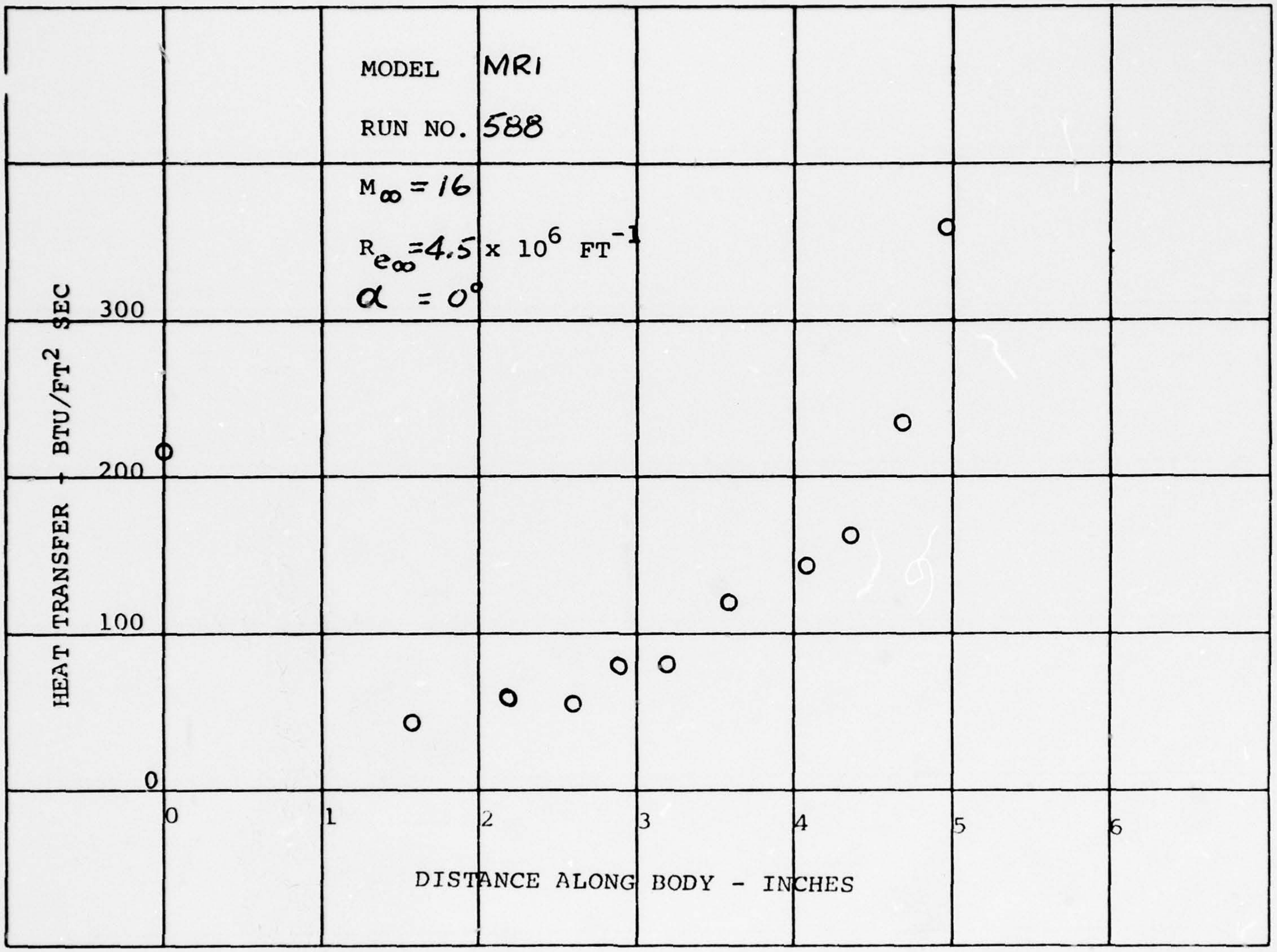
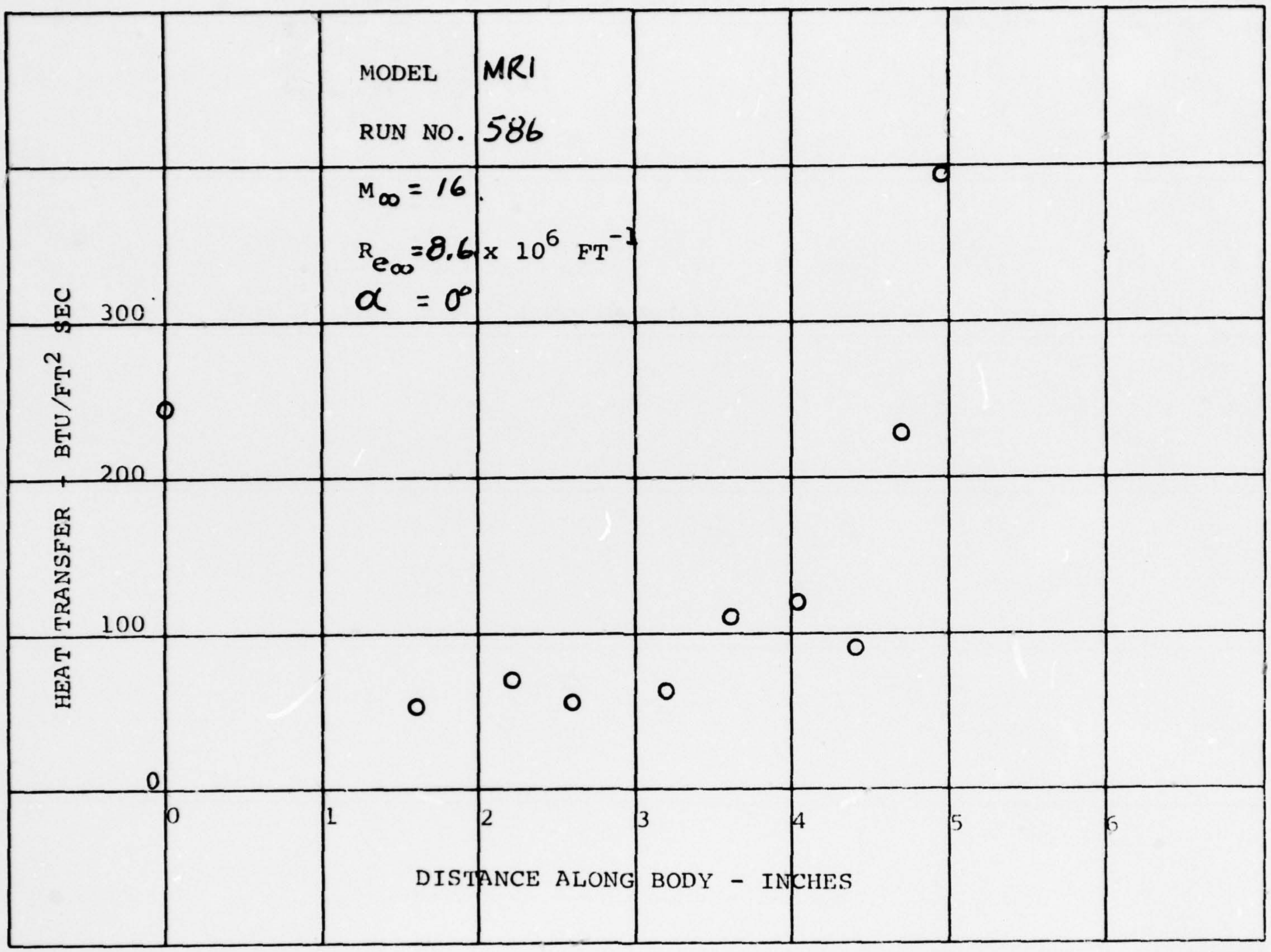


FIGURE NO. 15

HEAT TRANSFER ON CONCAVE BICONIC



AVCO

FIGURE NO. 16

HEAT TRANSFER ON CONCAVE BICONIC

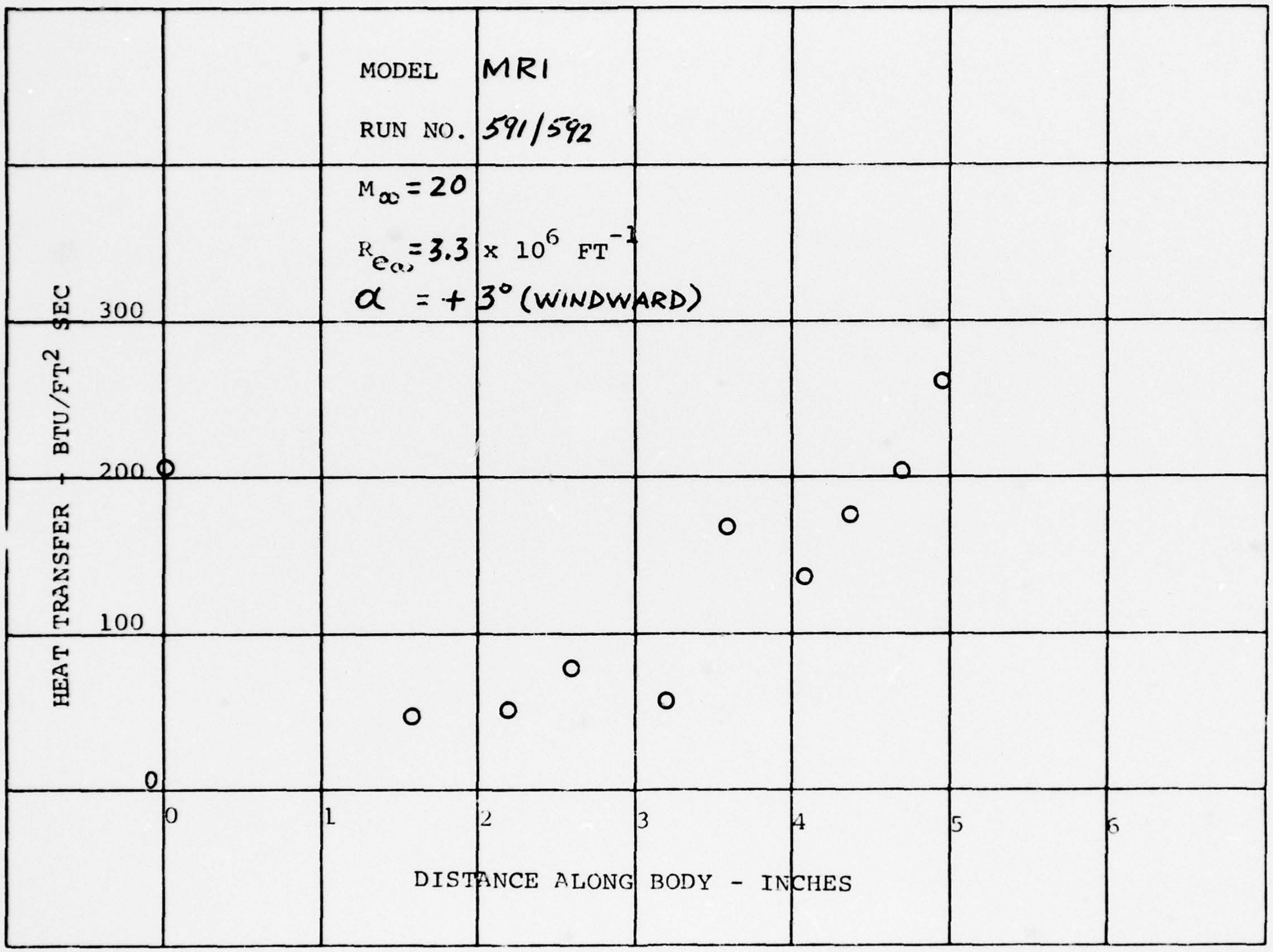
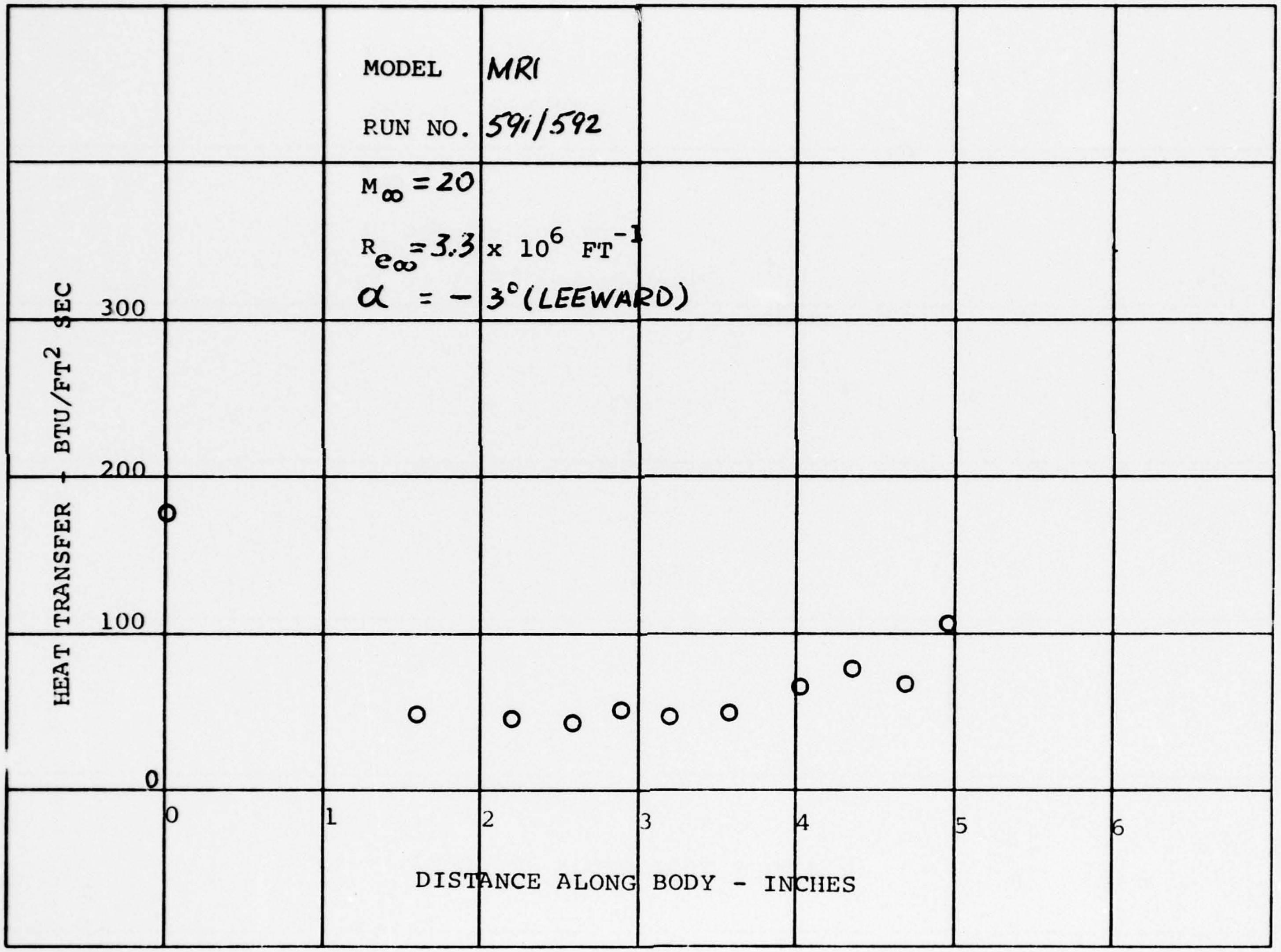


FIGURE NO. 17

HEAT TRANSFER ON CONCAVE BICONIC



AVCO

FIGURE NO. 18

HEAT TRANSFER ON CONCAVE BICONIC

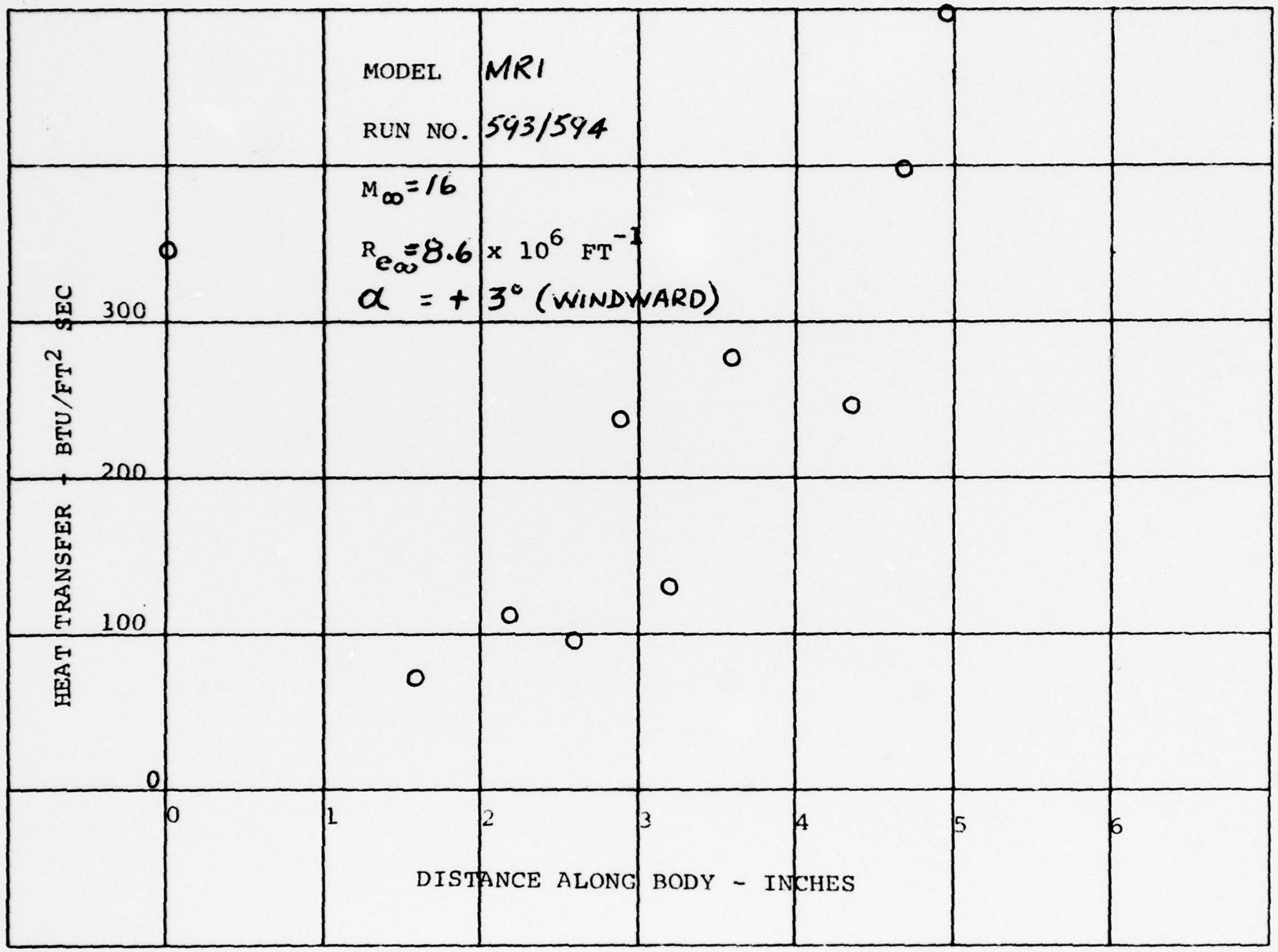


FIGURE NO. 19

HEAT TRANSFER ON CONCAVE BICONIC